AERODERIVATIVE MARINE AND OFFSHORE BASED POWER

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SLIDE 1

I am here to talk about a different application for aeroderivative gas turbines, and that is the marine and offshore power area. I will try to narrow that down a little bit.

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For today we are going to talk about commercial marine applications such as fast cargo ships and an area that's very popular today, large fast ferries.

SLIDE 3

In offshore, you are really talking about applications on oil rigs or production ships that are used in conjunction with off shore oil production. I will show a little about some of the applications. I wish to start off with one of the platforms. This is the North Sea and this is an oil platform in the Norwegian sector, a relatively old application, it was installed in the 70's. To give you an idea of the size, these white things on this end are six story dormitories. That's where the crew live when they are not on duty. You can see it's a pretty massive structure and is about 90 to 100 feet above the water. This particular one uses six aeroderivative gas turbines that happen to be LM2500s from GE. Three of them are generating electricity and three of them are used to drive compressors for pumping gas or re-injecting gas back into the wells.

SLIDE 4

This is the Marathon Bray platform. This again is in the North Sea but it is in the English sector. This particular platform uses three General Electric LM5000 engines in the gas compression area. It probably also has some aeroderivatives doing the electric power generation. I know they are not ours and being in the British sector I would guess they were supplied by Rolls Royce.

SLIDE 5

Now we move into the area of marine propulsion. This is a Ferry, called "*Foil Cat*" which was built by Keverna. There are two of them in operation today in Hong Kong and each holds about 400 passengers. It will do 50 knots and is 40 meters long. It is a Hydrofoil craft and has two LM500 GE engines on it at 6000 horsepower a piece. Just to give you an idea of the duty cycle, this ship runs about six trips a day and each trip takes about 45 minutes. It's like running a commuter airliner except that you go up in power and stay at max power for most of the run.

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For those of you with large disposable incomes, this is *"Echo"* . It is a luxury yacht, 65 meters long with a top speed of 38 knots. It's powered by one GE LM1600 gas turbine of about 20,000 horsepower and it also has two diesels. It operates on the diesels for most of the low speed operation. If they want to get up to the speed of 38 knots then they also run the gas turbine.

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For those of you with really large incomes, I suggest the *"Destriero"*. It is really one of a kind. It is 67 meters long and was built with one objective and that was to set the Trans Atlantic speed record. This ship has three GE LM1600 gas turbines that provide 60,000 horsepower. That's about 1,000 horsepower per meter of length. In 1992 it did set the speed record from Gibraltar to New York at an average speed of 53 knots. This resulted in winning the "Blue Riband Trophy", so they have a pennant displayed on the ship. You see a lot of corporate sponsoring on the boat. That's the fun part of marine applications.

SLIDE 8

More practical, is the "Aqua Strada. It is a ferry and three were built in Italy. They are like the *"Echo"* in that they use a gas turbine plus some diesels. In this case it's an LM2500. It is a fairly large ship and is 100 meters long. It carries 450 passengers and up to 150 cars. It operates between Rome and the port near Rome, and Sardinia and runs about three and a half hours for that trip. It's one of the more modern ferry boats, it's a mono-hull.

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The last one that I am going to show you is the "Stena". It's a 124 meter ferry. It's a catamaran and utilizes two LM2500's and two LM1600's. A pair of engines is mounted in each of the two hulls and they drive water jets. This is a large ferry that handles about 1500 passengers and up to 375 cars. It will do a minimum of 40 knots, and it has operated up to 50 knots. It operates in the Irish sea, making between 9 to 10 trips a day at about one hour and a half each. There is one ship that operates from Wales to Dublin and there is another that operates from Scotland into the Belfast area. The reason that we are starting to see so many of these applications is that the gas turbine aeroderivatives are starting to replace diesels. Some of the reasons for that are shown on this chart.

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Gas turbines, when compared to diesels, do provide advantages in terms of lower weight, more power capability, and lower operating cost. The payoff for the operators, as shown on the right side, are to get more payload on the ship or to take up less space on the platform and you can see how crowded those platforms are. These are some of the advantages, but the bottom line is lower life cycle cost.

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In terms of weight and volume, if you compare comparable diesels and aeroderivatives there's about a seven to one differential in terms of weight for a given power size between the diesel and the gas turbine and because of the heavier weight the diesels tend to require some additional plant weight. By the time you get all done you are talking somewhere between 12 and 15 times the amount of total installed weight for the diesel system compared to the gas turbine. That's why these gas turbines are popular for platforms and for ships. There's also, a significant advantage in terms of the volume. There's roughly a 4 ½ or 5 to 1 advantage in terms of the volume of the total package that you will have to install to put a comparable gas turbine, instead of a diesel, on either a ship or a platform. With both weight and space being a premium for these applications, gas turbines have significant advantages and are becoming very, very popular.

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Some of the other advantages that gas turbines tend to bring in are life cycle cost. Part of that is in the initial installation. Because they are smaller, there is less platform size or ship size that is occupied by the power plant and that cuts down on the cost. Gas turbines have less parasitic power demand than diesels so that also helps. Gas turbines also have less maintenance cost so there are a number of items that add up to lower life cycle cost.

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In terms of maintenance requirements there are advantages that translate over from the aircraft heritage. The aeroderivative engines are relatively easy to maintain because they lend themselves to on condition maintenance and on board diagnostic systems that allow you to trend performance and decide which components need to undergo maintenance. The refurbishment varies a bit depending on the application. The numbers that are being shown for a platform installation where they might be burning liquid fuel. We get about 12,000 hours between hot section refurbishments.

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The advantage for an aeroderivative in this type of an application is that you can pull the engine out of its enclosure, pull the turbine out and replace it with a spare turbine and have it back on line in about a day. You can do maintenance on a platform or on the ship relatively quickly to keep the system operating. One of the other big factors in availability, is that the capability to do under-cowl maintenance on the aircraft also carries over, so you can keep the units up and running.

SLIDE 15

Just a little bit about GE - LM family of engines. They are all aeroderivatives. We currently have five products that range from the LM500 at 6,000 horsepower that was derived from the TF34, up to the LM6000 at 42 megawatts or 56,000 horsepower, which was derived from the CF6-80C2. The largest engine in our stable in terms of numbers is the LM2500, that was derived from the CF6/TF39 engines. It was originally introduced at 20,000 horsepower and was increased gradually up to about 31,000 horsepower over a period approximately 25 years. Recently, we have added a zero stage onto that machine and increased the horsepower rating up to close to 40,000 horsepower. The first of these will go into commercial service very shortly. Recently, we ran the first engine up to 47,000 horsepower.

SLIDE 16

To give you an idea of the amount of operating times associated with aeroderivative applications. This is our fleet right now. I did not realize until I arrived here that the LM500 fell off the chart some place so I only have four of them shown. All together we're just a little bit short of 2,000 engines in these four models with a total of about 23 million operating hours. It is interesting that in the case of the LM2500 we have actually built more aeroderivatives than we built of the original aircraft engine. We are up over 1400 on that compared to 1130.

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To show you what we have accomplished in the commercial marine and offshore applications, there are 21 marine applications that involved a total of 47 engines. In offshore, which is a bigger market, right now we are on 56 different platforms or production vessels with a total of 182 engines.

SLIDE 18

Now a few words about secondary flows and seals that are the topics of this conference. This chart shows the CF6-80C2, which was the commercial engine parent on the top and the LM6000 on the bottom. As you can see there's not a lot of difference and that's probably the key item. We took the fan off and added two extra stages of low pressure compressor on the front. We have a different frame in between compressors, but fundamentally, the bearing systems and seals on the front are the same as they are on the parent. All of the core is the same. The LM6000 has a different fuel system to handle natural gas fuel with steam used as an emission control. On the back end we have designed a new frame and installed a balance piston to rebalance the axial rotor thrust. Fundamentally, all the seals and secondary air systems throughout the engine are the same as they were on the aircraft engines, so the same design requirements exist.

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Perhaps the one thing that is a different is that Marine and Industrial applications will tend to run at high power almost all of the time. Generally, a little lower than takeoff power in terms of firing temperatures, but in terms of compressor discharge and cooling air temperatures, they are basically the same as take off temperatures on a flight engine. We run them constantly. There are some more variables, particularly, of the rotor thrust management. Electric power generation is at constant speed while ship propulsion is on cubic load characteristic. You end up operating the components in a different regime than you would in power generation. For mechanical drive, in theory, you could run any combination of speed or power. The driven load really dictates what it is. We have found, on some of those applications, that we've had to go to active systems on balance pistons where we will sense pressures in the piston cavity and then we use a control valve to set and maintain the pressure we want.

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In summary, the marine propulsion and offshore areas are two rapidly growing markets for aeroderivative gas turbines. The reason is that they have significant bottom line advantages over their principle competition on these applications. The secondary flows and seals demands are very similar to the aircraft engines and the and technologies are needed for these applications.

QUESTIONS:

Q. You mentioned the operating cycle cost, but not specifically about SFC's. Do the diesels still have an advantage over the aeroderivatives?

A. The diesel still has some advantage particularly as you pull the power back. At max power they are pretty close, but there is some advantage for the diesel when you have to throttle back the gas turbine. The diesels are not rolling over. They've done work to try to increase their power capability, to improve their power per cubic meter, and also their performance. Above 20,000 HP it gets tough for the diesel to compete with an aeroderivative gas turbine.

Aeroderivative Marine and Offshore Based Power Engine Technology

J.C. Guion
10/23/96

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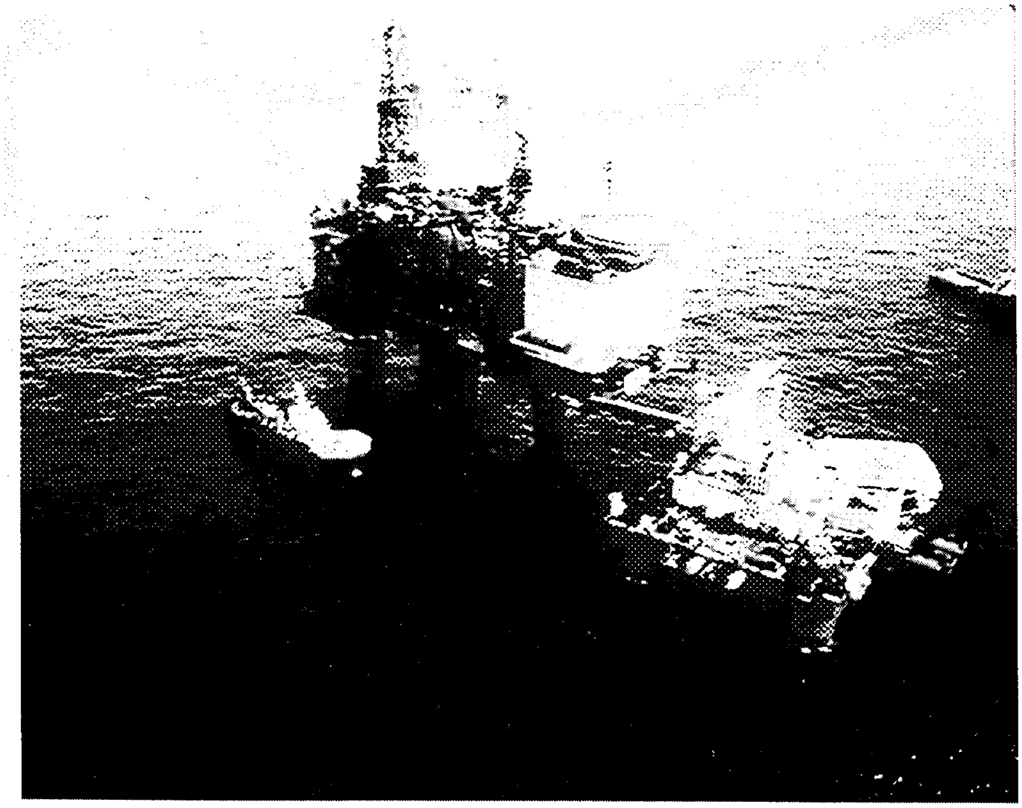
For This Presentation:

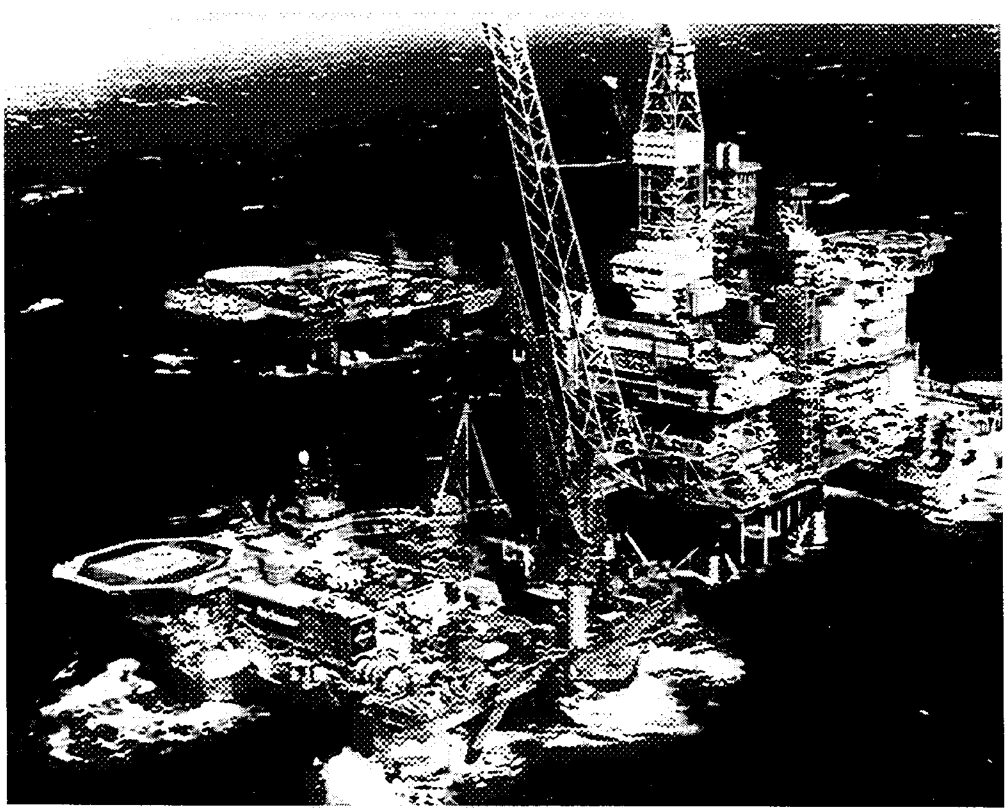
Marine: Commercial Marine such as Fast Ferries, Yachts, Cruise Liners or Fast Cargo Ships

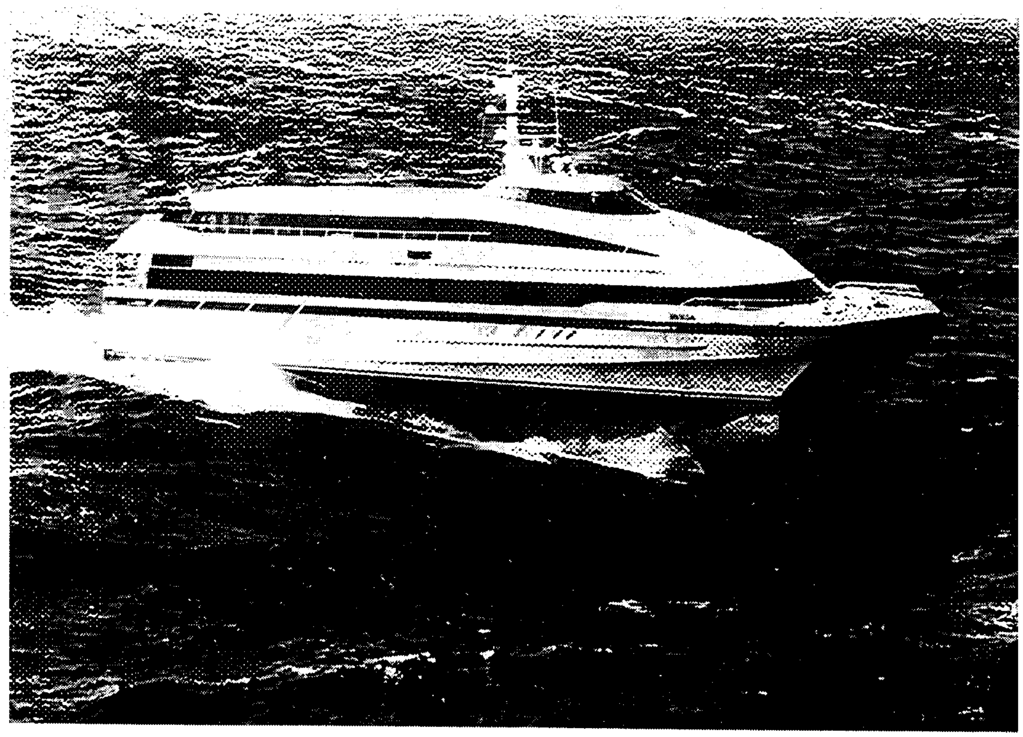
- Differentiator from most military applications is the percentage of high power operation

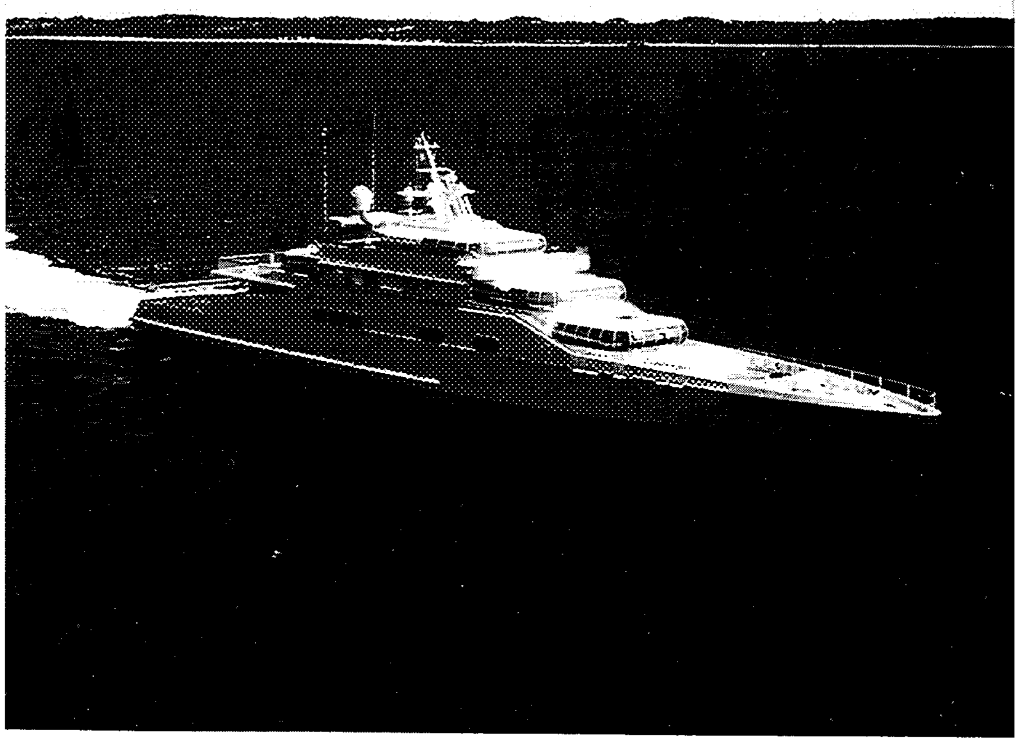
Offshore: Oil and gas platforms, floating production ships

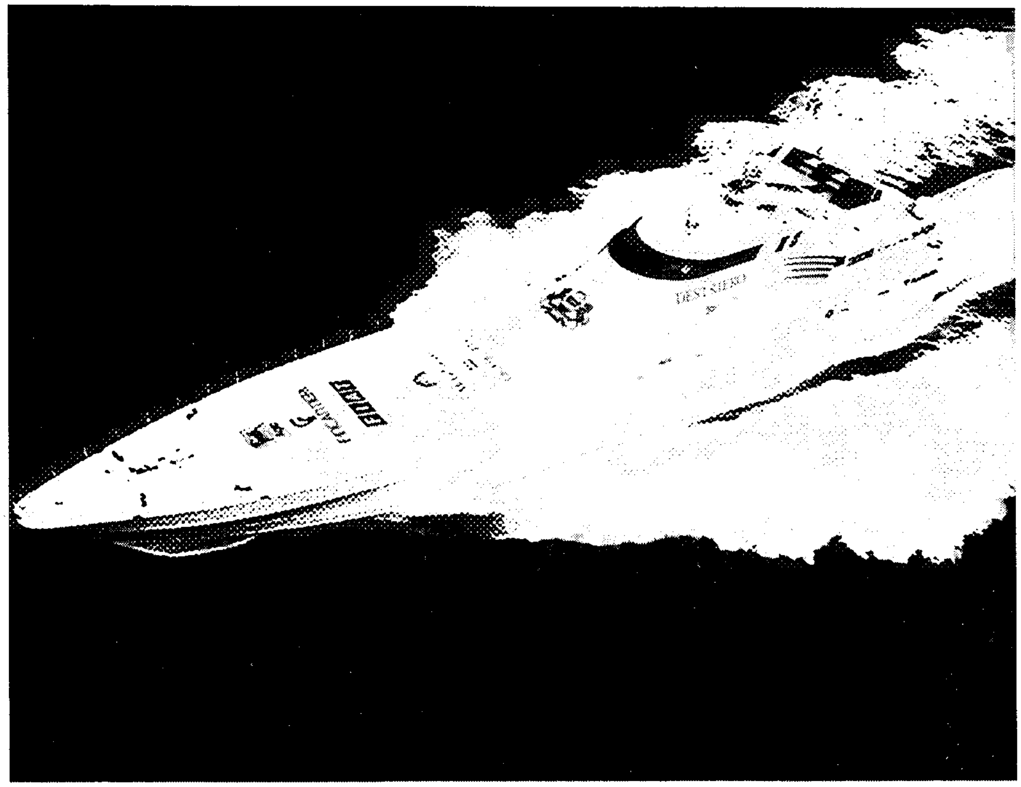
- Units used for electrical power and gas compression/reinjection

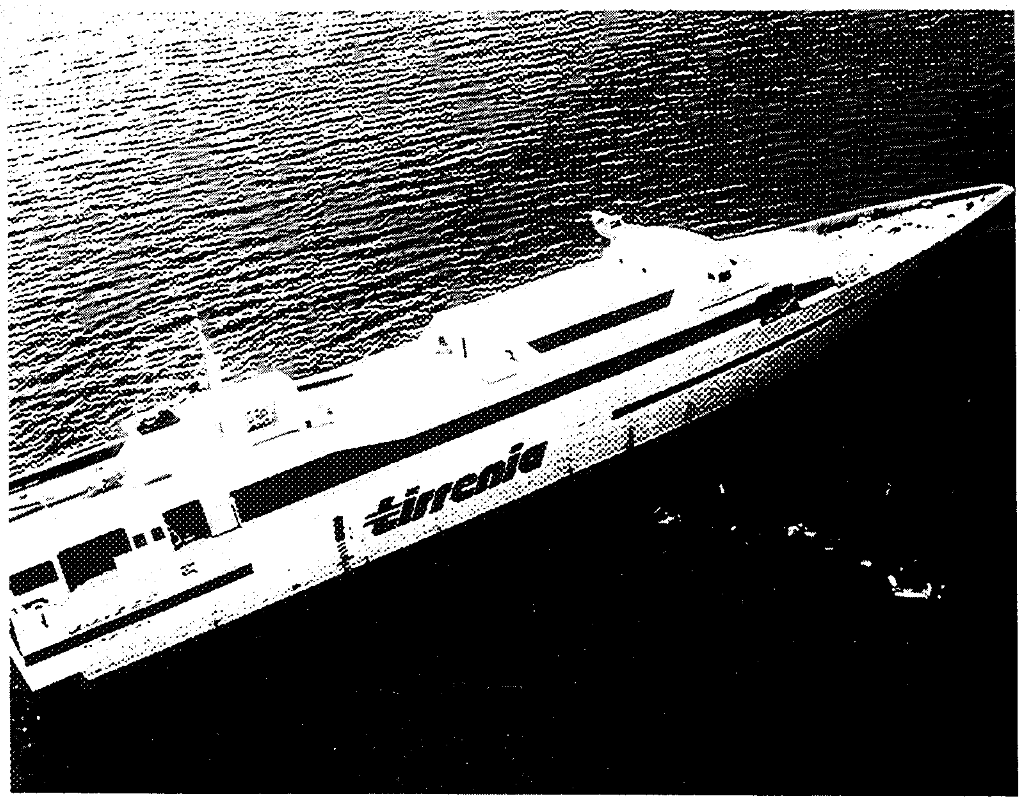








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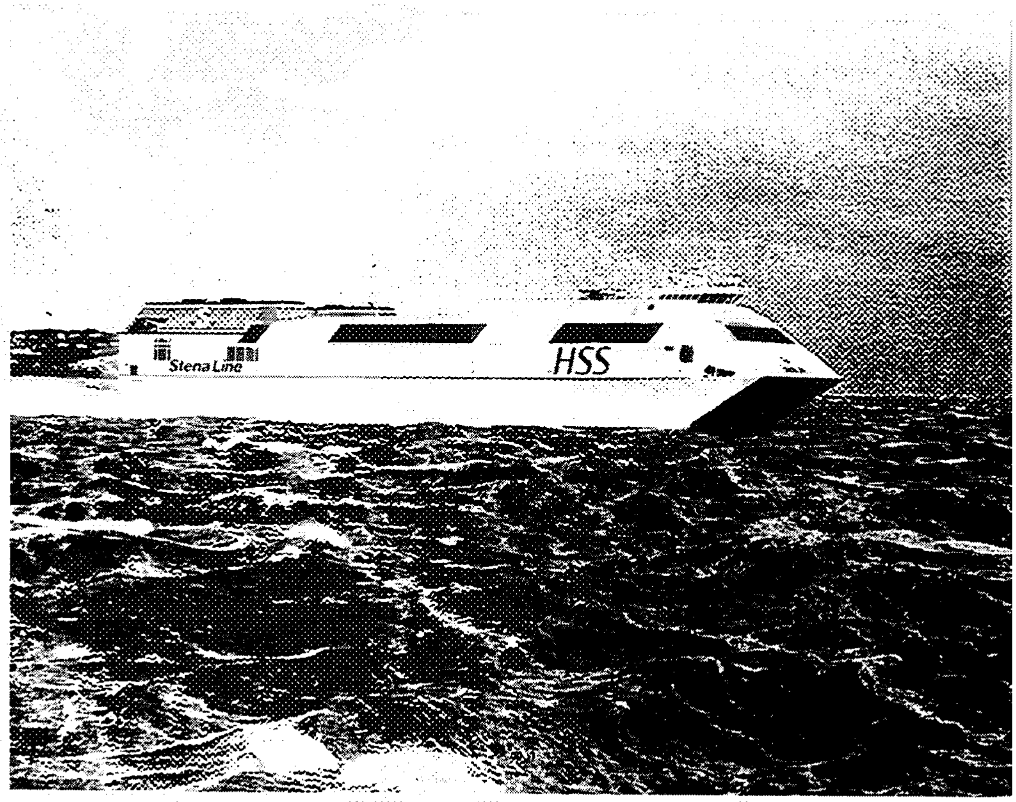

Stena Line
HSS

Aeroderivative Gas Turbine Advantages Relative to Diesels

- Lower weight, Smaller volume → More payload/ Reduced platform size
- Higher power → Higher speed/less complexity
- Lower investment cost
- Lower consumables cost → Lower total life cycle cost
- Lower maintenance cost

Gas Turbine Weight and Volume

- Lower weight
  - Gas turbine plant lower specific weight
    - 1.0 mton/MW for GT
    - 6.9 mton/MW for diesel
  - Factor for total plant is about 2 -3:1
  - Weight savings for nominal 24 MW plant is over 100 mton
- Lower volume
  - Gas turbine plant lower specific volume
    - 2.5 m^3/MW for GT
    - 12.5 m^3/MW for diesel
  - Fewer engines
  - Less silencing, less ventilation

Life Cycle Costs

- Installations cost less for gas turbines system
  - smaller foundations - fewer engines and less weight
  - less auxiliary support
    - no separate lube oil system
    - no cooling water requirements
  - fewer inlet/exhaust air systems
- Consumables costs
  - Power requirement less for gas turbine at same payload
  - Lube oil consumption cost 1/10 that of diesel
- Maintenance costs
  - GT average maintenance cost 30 to 50% less than diesel
- Total operating cost
  - GT operating cost comparable or less than diesel

Maintenance Requirements

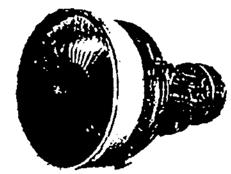
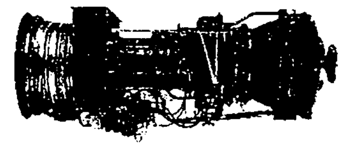
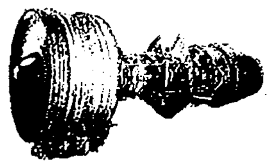
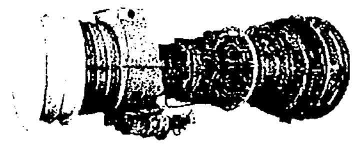
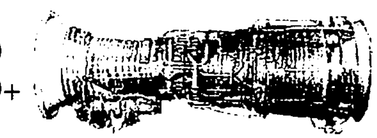
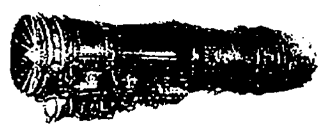
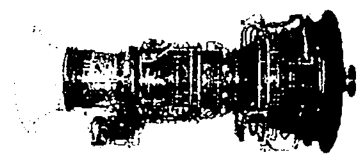
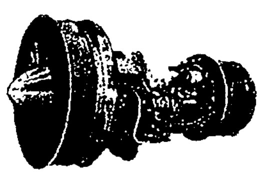
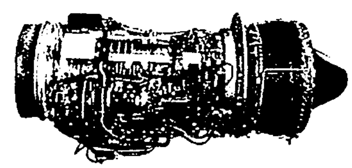
- Condition based maintenance for GT's
  - engine health continuously checked and trended
  - maintenance actions only when required
- On board requirements
  - scheduled checks and automatic parameter recording
  - minor external item corrective replacement
- Depot refurbishment requirements
  - Hot section components (combustor/high pressure turbine) - nominally at 12,500 hours
  - Overhaul of gas generator - 25,000 hours
  - Power turbine overhaul - in excess of 50,000 hours

Availability

- High availability critical to these operations
- Availability related to reliability/maintainability
- Aeroderivative engines inherently reliable
  - flight safety considerations
  - condition based maintenance assesses status of engine
- Maintainability features ensure quick repairs
  - minimal "on board" maintenance
  - short repair times
  - quick change out for major maintenance action (modular construction)

GE Marine and Industrial Engines

Genealogy

		Applications			Power Output MW/SHP Thermal Efficiency
CF6-80C2		MD-11 B747, 767 A300/310/330	LM6000		44.9/60,150 42.7%
CF6-50		DC-10 B747 A300	LM5000		35/47,000 38.0%
TF39/CF6-6		C-5 DC-10	LM2500 LM2500+		LM2500: 23.3/31,200 LM2500+: 29/39,000 37-39%
F404		F/A-18 F-20 F-117	LM1600		14.3/19,200 37%
TF34		S-3A A-10	LM500		4.2/6,000 32%

Only Turbine Manufacturer with Complete Line of Aeroderivatives for Marine & Industrial Applications

PPT-82522-072496 (M&IEXOV)

Proven Experience Worldwide - All Applications

LM Aircraft Engine	Aeroderivatives Number of engines	Aeroderivatives Operating hours	Aircraft Engines Number of engines	Aircraft Engines Operating hours
LM1600/F404	128	1,003,000	3,400	5,200,000
LM2500 (TF39/CF6-6)	1,465	20,294,000	1,130	28,750,000
LM5000 (CF6-50)	98	2,447,000	2,140	81,555,000
LM6000 (CF6-80C2)	127	400,000	2,055	24,562,000

GE M&I Commercial Marine and Offshore Power Installations

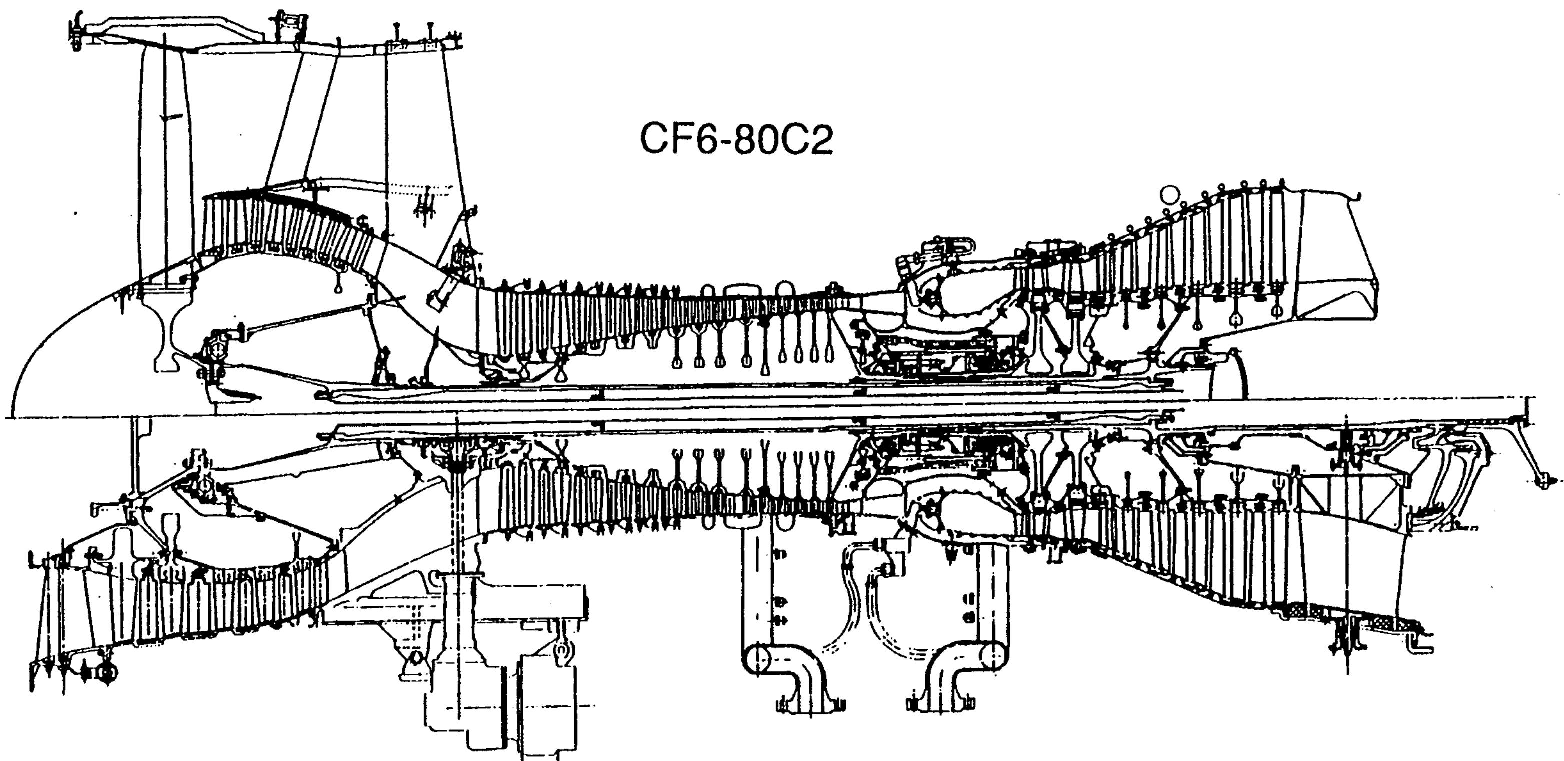
Commercial Marine

21 vessels	47 engines

Offshore Power

56 platform/vessels	182 engines

Comparison of LM6000 Gas Turbine/ CF6-80C2 Turbofan



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Secondary Flows & Seal Design

- Secondary flow and seal designs are critical to aeroderivative engines
  - Thermodynamic impacts similar to aero engine at take-off
  - Challenging task to model secondary and flowpath flows and pressures to predict bearing load - more variables than aircraft engine
  - Rotor thrust management dependent upon application
    - Electric power generation — speed vs load is unique
    - Shipboard propulsion — speed vs load variable (within limits)
    - Mechanical drive — speed vs power infinitely variable
  - Active balance piston pressure control required for some applications

Summary

- Marine propulsion and offshore power generation are growing markets for aeroderivatives
- These machines offer significant bottom line advantages over the competing power sources
- Challenges for design of secondary flow systems and seals are very similar to aircraft engines and just as important